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Electron saturated velocities in silicon carbide polytypes for drift direction along crystal axis

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Introduction

The saturated drift velocity is a very important parameter of semiconductor crystals. It determines frequency limitation of semiconductor devices and consequently the range of the most effective application. Silicon carbide polytypes are not exclusion. Up to the present such velocities have been determined for two polytypes 4H and 6H SiC for direction perpendicular to crystal axis [1]. As it was shown these values were equal. But there is anisotropy of electrical properties in silicon carbide polytypes for the direction along and perpendicular to the axis. Besides the crystal axis is the axis of the natural superlattice (NSL) axis too. As well known the drift velocities in artificial SL depend very strong on parameters SL and change from 10^6 cm/s for relatively wide [2] miniband to 10^4 cm/s for narrow one [3]. Earlier we have shown that NSL creates such electron spectrum in silicon carbide polytypes that led to the existence such effects as Bloch oscillation, electro-phonon resonances, interminiband tunnelling and others. Evidently the saturated drift velocities have to experience an influence of NSL. But such data were absent in literature. Briefly some data on this question were given in [4]. A technical experimental difficulties did not allow to curry on such experiments. Usually used method of the current saturation was not used for geometry when a current was parallel to the axis because of unfavourable conditions of the Joule heat removing probably. But as far as a lot of devices including power high frequency devices are fabricated or will be fabricated for such geometry the determination of saturated drift velocities is an important problem both from fundamental and apply point of view.

Experimental method

Our method is based on the following idea. When in an experimental structure with space charge limited current a drift current regime is realised the drift velocities may be obtained. This regime for one dimensional case may be described by two equations:

$$d^2V/dX^2 = \rho/\varepsilon_s \tag{1}$$

$$J = \rho v \tag{2}$$

where V, X, ρ, ε_s, J, v the voltage on a specimen, the coordinator along a current, the space charge density, the dielectric constant of semiconductor, the current density, the drift velocity respectively. By some standard transformations we can show that a current–voltage characteristic consist of two regions: the first region where drift velocity is changed with changing of an electrical field and the second one where velocity is

saturated and is not changed with the field. If we consider the velocity equal to

$$v = \mu V/w \tag{3}$$

then I–V characteristic on the first region will be

$$J = 2\epsilon_s \mu V^2/w^3. \tag{4}$$

Here μ, w are the mobility of carries, the length of the specimen respectively. It should take into account that in (4) may be a function of the field and then a real I–V characteristic will not correspond to (4).

On the second region where $v =$ const the I–V characteristic will be the following:

$$J = 2\varepsilon_s v_s V/w^2 \tag{5}$$

where v_s is the saturated velocity. Thus, when the drift velocity is saturated, we have to observe the linear region on I–V characteristic.

1 Experimental structure

The original three-terminal N^+-p-N^+ structure will be used for this investigations. The structure consists of three regions, according to the transistor terminology base, collector and emitter. The middle region or base contains the silicon carbide polytype intended for investigations. It is doped by the deep acceptor impurity scandium for obtaining of the minimal free hole concentration about $10^{10}\,\mathrm{cm}^{-3}$ for 300 K. The base is located between two n-regions, collector and emitter. The collector and emitter p-n junctions are the same, but they differ from the usual ones.

The forward biased junction is able to be opened only by a direct bias or by pulses with duration $\tau_p > 10^{-2}$ sec. Naturally for lowering of the potential barrier, it is necessary to deionize the deep acceptor impurity in the space charge region. The characteristic time of this process is more than 10^{-2} sec at a hole concentration about $10^{10}\,\mathrm{cm}^{-3}$. But when the potential barrier is lowered, injection, which is an uninertial process, can be accomplished by pulses with $\tau_p \ll 10^{-2}$ sec.

There is the following situation in the reversal biased junction. At the reversal direct bias, the field in p-region is screened by ionised acceptor impurities with $N_a - N_d \sim 10^{17}\,\mathrm{cm}^{-3}$. For voltage about several tens of volts, the length of screening is less than 10^{-4} cm and the field in the p-region is nonuniform. However the screening length is larger than 10^{-1} cm in accordance with the hole concentration of about $p < 10^{10}\,\mathrm{cm}^{-3}$ at the reversal pulse bias with duration $\tau_p \ll \tau_i$. Here τ_i is the time of ionisation for the acceptor impurity. Therefore, the width of the p-region of about $(5-10) \times 10^{-4}$ cm allows to obtain a practically uniform electric field. The field has to be directed parallel to the superlattice axis.

The working principle of the structure is the following: the collector junction is reversal biased by the pulse voltage with $\tau_p \sim 10^{-7}$ sec. The emitter junction is forward biased by direct voltage which causes injection into the base. The electric scheme is analogous the transistor with common emitter. The pulse field spreading through the base reaches the open emitter junction and causes injection into the base. The injected current increases with the pulse voltage, but it is able to be limited by the decrease of the bias between emitter and base.

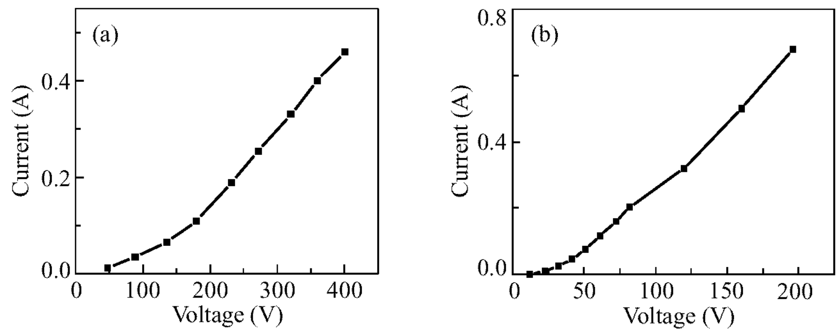

Fig 1. (a) I–V characteristic of the 4H-SiC tree terminal structure. (b) I–V characteristic of the 6H-SiC tree terminal structure.

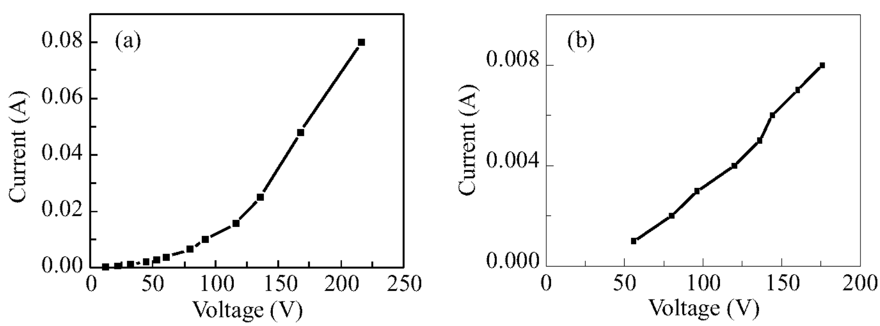

Fig 2. (a) I–V characteristic of the 8H-SiC tree terminal structure. (b) I–V characteristic of the 21R-SiC tree terminal structure.

Thus, there is the uniform electric field in the p-region and current intensity is controlled independently on the field in the base region. It is highly important that this experimental method allows to conduct measurements with the electron current only without the current associated with the holes.

2 Experimental results and discussion

The electronic transport in the experimental structure used for the measurements is determined by the transit time mechanism. It is known that the current-field characteristic inherent for the transit-time conduction mechanism includes the linear region associated with the space charge limited current. This region is observed when the concentration of the carriers injected is as large as an ionised impurity concentration in the base. In a usual situation such a condition is met at a very large current density and a strong electric field when the carriers drift velocity reaches its saturation value.

The feature of the experimental structure used for the study is an ionised impurity concentration so low that the space charge limitation of the current takes place at low current density when the electric field is insufficient for the carriers velocity saturation.

In this paper we present the data of I–V characteristics investigation for the polytypes 4H, 6H, 8H and 21R SiC. The current-field characteristic of the experimental structure may include the following regions connected with the space charge limitation of the

current injected: the region with $j \sim V^2$ (4) and the region with $j \sim V$ associated with electronic velocity saturation (5). These regions are identified in the experimental I–V characteristics clearly (Figs. 1-2). The values of high-field mobility obtained by the processing of the characteristic region with $j \sim V^2$ were found to be 3.1 cm^2/Vs, 4.5 cm^2/Vs and 6.4 cm^2/Vs for polytypes 8H, 6H and 4H respectively.

From the analysis of linear region of I–V characteristics the values of saturated electron drift velocities for 4H-, 6H-, 8H- and 21R-SiC were obtained which are approximately equal to 3.3×10^6, 2×10^6, 10^6 and 4.4×10^3 cm/sec correspondingly. The low values of velocities, which are significantly smaller than the well known value $v_s = 2 \times 10^7$ cm/sec for F⊥C [1] are of special interest. But these values qualitatively correspond to the anological results for artificial SL's. Both for these SL and for the NSL of SiC polytypes the saturated drift velocity drops with decreasing of the miniband width.

Thus, the presented results are the new evidence of minizone structure of electron spectrum in SiC polytypes and the new basis of data for a device project. The partial financial support of Russian Foundation of Fundamental Research project 97-02-18295 and Russian Science Program "Physics of Solid State Nanostructures" project 97-1038 is gratefully acknowledged.

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